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TITLE

TIME-SEQUENTIAL COLOR SEPARATOR AND LIQUID CRYSTAL PROJECTOR USING THE SAME

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a color separator, especially to a time-sequential color separator and a liquid crystal projector including the color separator.

Description of the Related Art

Conventional color separators are normally classified into mechanical type and electronic type. The former uses various color filters to mechanically separate color lights from an incident white light. Such a mechanical type color separator normally has a complex structure, a big volume and all of the drawbacks due to mechanical movement. The latter is constructed by electronic circuits and light valves. Therefore the quality of an electronic type color separator is related to the response speed of light valve, the transmittance, the color purity and the contrast ratio.

A conventional electronic type color separator as disclosed in U.S. Patent No. 4,232,948 by Shanks uses a liquid crystal light valve, which can change the polarization of a light passing therethrough, and a retarder having a birefringence effect to change the observed color of the light passing through the device. The transmittance, the switching speed and the color

purity obtained by such a color separator is not desirable. Furthermore, in U.S. Patent No. 5,347,378, Handschy et al. utilize a structure which combines a color-selective filter with a fast-switching liquid crystal light valve. However, the transmittance and the color purity obtained by the color separator are still not satisfactory.

Accordingly, in "High Brightness Saturated Color Shutter Technology," SID Symposium, Vol. 27, p.411, 1996 by Sharp and Johnson and "Retarder Stack Technology for Color Manipulation," SID, 1999, by G.D. Sharp and T.R. Brige, a time-sequential three primary color switch having a high response speed and a saturated chromaticity, which combines a polarization retarder stack (PRS) and a fast-switching liquid crystal light valve, is disclosed. The device disclosed in U.S. Patent No. 5,751,380 was developed by ColorLink, Inc., as a commercial product known as "ColorSwitch α". The relevant description can be referred to in "High Throughput Color Switch for Sequential Color Projector," SID 2000 Digest, p.96, 2000, by G.B. Sharp, et al.

Fig. 1 illustrates the structure of the color switch disclosed by G.B. Sharp, in which the reference numeral 10 and 20 respectively represent visible light polarizer, the reference numeral 1, 2, 3 respectively represent light valve units of red color, green color and blue color. The red-color light valve unit 1 includes a ferroelectric liquid crystal (FLC) panel 100, a front PRS 11 and a rear PRS 12. The green-color light valve unit 2 includes an FLC panel 200, a front PRS 13 and a rear PRS 14. The blue-color light valve unit 3 includes an FLC panel 300, a front PRS 15 and a rear PRS 16. A time-sequential pulse 400 is respectively connected to the FLC panels 100, 200

and 300 to emit the polarized red light, green light and blue light in sequence.

Refer to Fig. 2, which is relevant prior art disclosed by the inventor and filed as a patent application entitled as "FIELD SEQUENTIAL COLOR PROJECTION DISPLAY", whose application number is 09/524,051. In this prior art, the dichroic prisms 90~95 are used for color separation and recombination. The three FLC panels 70, 72 and 74 are controlled by a time-sequential pulse 110 to emit the light beams of red color, green color and blue color in sequence. The switching speed of the field sequential color projection display system can achieve 0.05 msec. Furthermore, there is substantially no energy loss for the light beams of three primary colors since the system is constructed by dielectric interference filters. However, the alignment of this prior-art system is difficult.

The drawback of the above-described prior arts using FLC panels is the limitation of contrast ratio when a light beam passes through the FLC panel. Therefore, in order to overcome the shortcomings of the prior art, it is important to increase the contrast ratio of the light valve, as well as the response speed of the FLC panel.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a fast time-sequential color separator that can be fast switched to output various wavelength ranges of lights having high color purity and high contrast ratio.

A full color LCD projector can be constructed by the color separator, a transmissive or reflective fast-response display

element such as a liquid crystal light valve, and other elements such as micro-mirrors, etc.

This invention takes advantage of non-absorption of the interference polarizer and large aperture ratio, high contrast ratio and fast response speed of the reflective ferroelectric liquid crystal panel to constitute a three primary color separator. The polarized incident white light is separated into the light beams of three primary colors by the color filters. A time-sequentially-controlled single-pixel reflective FLC panel then sequentially reflects the color light beams to a single panel of FLC display. The frame frequency of the FLC display can be larger than 0.15 MHz. The CIE coordinates of the three primary colors obtained by the color separator of this invention are (x=0.65, y=0.31), (x=0.28, y=0.69) and (x=0.12, y=0.09), respectively.

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BRIEF DESCRIPTION OF THE DRAWINGS

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~~The present invention can be more fully understood by reading the subsequent detailed description in conjunction with the examples and references made to the accompanying drawings, wherein:~~

Fig. 1 is a diagram illustrating a prior-art color separator;

Fig. 2 is a diagram illustrating another prior-art color separator;

Fig. 3 is a diagram illustrating a color separator according to one embodiment of this invention;

Figs. 4A to 4F are spectral diagrams of the dichroic filters in the prisms of Fig. 3;

Fig. 5 is a diagram illustrating a color separator according to another embodiment of this invention;

Fig. 6A to 6F are spectral diagrams of the dichroic filters in the prisms of Fig. 5;

Fig. 7 is a diagram illustrating a liquid crystal projector including the color separator of this invention;

Fig. 8 is a diagram illustrating another liquid crystal projector including the color separator of this invention; and

Fig. 9 illustrates the CIE coordinates for the light beams of three primary colors obtained by using the color separator of this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Fig. 3, this invention includes a prism module that is constructed by six dichroic prisms 120, 122, 124, 126, 128 and 130, that separate an incident light into various wavelength ranges of light beams which are emitted from various prisms of the prism module; ferroelectric liquid crystal panels 140, 150 and 160, respectively placed on emerging surfaces of the various wavelength ranges of light beams, for reflecting the various wavelength ranges of light beams to the prism module; and a power supply, respectively connected to the ferroelectric liquid crystal panels 140, 150 and 160, for fast-switching the liquid crystal panels, respectively, to sequentially emit the various wavelength ranges of light beams from the prism module. The spectrum of the dichroic prism 120 is as shown in Fig. 4A. The spectrum of the dichroic prism 122 is as shown in Fig. 4B. The spectrum of the dichroic prism 124 is as shown in Fig. 4C. The spectrum of the dichroic prism 126 is as shown in Fig. 4D.

The spectrum of the dichroic prism 128 is as shown in Fig. 4E. The spectrum of the dichroic prism 130 is as shown in Fig. 4F.

When a parallel-polarized white light is incident to the prism module, the red component Pr of the parallel-polarized white light passes through the prisms 120 and 122 and is incident to the FLC panel 140. When the FLC panel 140 is switch-on , the parallel-polarized red light Pr (indicated by solid line in the drawing) is reflected and converts into a vertical-polarized red light Sr, which is then reflected by the prism 122 to pass through the prisms 126 and 130 and emerges from the prism 130. When the FLC panel 140 is switch-off, the polarization of the parallel-polarized red light Pr is not changed, the parallel-polarized red light Pr is reflected by the FLC panel 140 to pass through the prisms 122 and 120. The reflected parallel-polarized red light Pr' emerges from the prism module along the incident optical path.

The green component Pg and the blue component Pb of the parallelly polarized white light is directed toward the prism 124 after it is reflected by the prism 120. The parallelly polarized green light Pg is reflected by the prism 124 to pass through the prism 126 and is then incident to the FLC panel 150. When the FLC panel 150 is switch-on, the parallel-polarized green light Pg is converted to a vertical-polarized green light Sg, which is reflected by prism 126 and emerges from the prism 130. When the FLC panel 150 is switch-off, the parallel-polarized green light Pg is reflected and maintains its polarization. The reflected parallel-polarized green light Pg' passes through the prism 126 and is sequentially reflected by the prisms 124 and 120 and emerges from the prism module.

The blue component Pb of the parallel-polarized white light is reflected by the prism 120 to pass through the prisms 124 and 128, and then incident to the FLC panel 160. When the FLC panel 160 is switch-on, the parallel-polarized blue light Pb is reflected by the FLC panel 160 and is converted to a vertically polarized blue light Sb, which is sequentially reflected by the prisms 128 and 130 to be emerged from the prism 130. When the FLC panel 160 is switch-off, the parallelly polarized blue light Pb is reflected by the FLC panel 160 and maintains its polarization. The reflected parallel polarized blue light Pb' passes through the prisms 128 and 124 and is then reflected by the prism 120 and emerges along the direction of the incident light Ip.

According to the description above, if a fast pulse voltage source is connected to the FLC panels 140, 150 and 160, the vertically polarized lights of red color, green color and blue color can be sequentially brought out from the right side of the prism 130.

According to another embodiment of this invention, the color separator is constructed as shown in Fig. 5, which is similar to the embodiment of Fig. 3. However, the incident light used in this embodiment is a vertically polarized white light Is. The spectrum of the dichroic prism 220 is as shown in Fig. 6A. The spectrum of the dichroic prism 222 is as shown in Fig. 6B. The spectrum of the dichroic prism 224 is as shown in Fig. 6C. The spectrum of the dichroic prism 226 is as shown in Fig. 6D. The spectrum of the dichroic prism 228 is as shown in Fig. 6E. The spectrum of the dichroic prism 230 is as shown in Fig. 6F.

Referring to Fig. 7, the color separator of this invention can be combined with a transmissive liquid crystal display module 170 and a projection lens set 180 to constitute a time-sequential full color liquid crystal projector. Another embodiment is as shown in Fig. 8, in which the color separator is combined with a reflective liquid crystal display module 190 and a projection lens 180 to constitute a time-sequential full color liquid crystal projector.

The CIE coordinates of the light beams of red color, green color and blue color of the full color liquid crystal projector using the color separator of this invention are plotted in Fig. 9. In the drawing, the triangular area indicated by the symbol "O" represents the gamut of the prior-art color switch called "ColorSwitch α", and the triangular area indicated by the symbol "Δ" represents the gamut of the color separator of this invention. It is found that the color separator of this invention can obtain color lights having a better color purity.

Compared with the prior arts, this invention has the following advantages:

(i) the contrast ratio of the color separator is improved since the FLC panels used are reflective liquid crystal panels.

(ii) the color separator has a simpler structure than that using a transmissive liquid crystal panel as shown in Fig. 2.

(iii) the manufacturing process is simple since no precision alignment is required.

(iv) the light can be reflected back along the incident optical path when the FLC panel is switch-off,

therefore it is not necessary to use any absorber to absorb the useless light.

Finally, while the invention has been described by way of example and in terms of the preferred embodiment, it is to be understood that the invention is not limited to the disclosed embodiments. On the contrary, it is intended to cover various modifications and similar arrangements as would be apparent to those skilled in the art. Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.